EFFECTS OF EXERCISE AND MENTAL FATIGUE ON RESPONSE INHIBITION IN EXERCISE-TRAINED VERSUS SEDENTARY COLLEGE STUDENTS

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EFFECTS OF EXERCISE AND MENTAL FATIGUE ON RESPONSE INHIBITION IN EXERCISE-TRAINED VERSUS SEDENTARY COLLEGE STUDENTS

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I dedicate this work to my Father, Raul Grosz and Mother, Linda Grosz who have supported all my decisions through out my life. They have helped become the woman I am today and I wouldn't have been able to be at Georgia Tech without their love and belief in me. I am so thankful for them and I dedicate my effort and persistence that was put into my thesis to them.

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LIST OF SYMBOLS AND ABBREVIATIONS

VAS	Visual Analogue Scale
POMS	Profile of moods state
CPT	Continuous performance test
HR	Heart Rate
RPE	Rate of perceived exertion
RPM	Revolutions per minute

ABSTRACT

The purpose of this study was to determine if fitness levels of individuals affect cognitive function. Specifically, this study seeks to show how response inhibition and accuracy are affected following a mentally fatiguing task. Response inhibition refers to the suppression of actions that are inappropriate and that interfere with goal driven behavior. It ultimately plays a large role in executive functioning and is linked to impulsivity. Response inhibition in reference to the continuous performance task (CPT) is measured in false clicks. The tasks for the CPT were completed after either a controlled period of rest or moderate-intensity exercise. Subjects were either Georgia Tech Division I track athletes or students leading a sedentary lifestyle. All subjects participated in two test protocols. Athletic subjects completed the resting protocol first, while sedentary subjects completed the exercise protocol first.

Subjects reported to the lab following an overnight fast. They completed an initial set of paper work where they signed a consent form, filled out a 24 hour history form and completed a Profile of Moods States (POMS) and Visual Analog Scale VAS form. After the first set of paperwork was complete, subjects took a 20-minute (CPT). The CPT is a neuropsychological test that measures an individual's sustained and selective attention. The length of the test is 20 minutes in order to induce mental fatigue. The goal of the test is to click in a white box when the letter T is seen. Immediately following the 20-minute CPT, subjects filled out a secondary set of paperwork. Once paper work was complete subjects either rested or exercised for 35 minutes. If subject was classified as an athlete, trial 1 was rest, while trial 2 was exercise. If subject was classified as a sedentary student,

trial 1 was exercise, and trial 2 was rest. After the subject completed either the cycling or resting portion they repeated the CPT for five minutes.

It was hypothesized that that the effects of moderate exercise positively affect the subject's performance on the CPT. I expect false clicks following the 5 minute CPT to be lower after exercising. I hypothesize that for both groups their accuracy should be higher after moderate cycling and that higher fitness level should decrease the level of mental fatigue experienced throughout the CPT.

RESULTS: Using a GLM univariate repeated measures ANOVA with between factor group and within factor time. The results of this study revealed significant differences at time point 3 (post exercise or resting 35 min after mental fatigue). The difference between conditions for false clicks (rest versus exercise) was significant (6.8 ± 2.6) ($p=.049$). This result suggests that exercise will help restore subject's ability to perform better than rest alone. For accuracy at time point 3, exercise increased accuracy (.75% ± .029) ($p=.062$) compared to rest. Although this p value is insignificant, $p>.05$, it follows a similar trend as false clicks (response inhibition) and could be influenced by low statistical power due to a sample size of $n=6$ $\alpha = .05$. Based on results, it appeared that trained athletes tended towards less mental fatigue (higher accuracy) throughout the entire length of the CPT.

CONCLUSIONS: With a limited sample size (six subjects stratified into two groups based on two fitness levels), these data indicate mental fatigue results in higher response inhibition (making more false clicks). Moderate exercise is more beneficial in reversing response inhibition compared to quiet rest and is potentially more effective for sedentary than trained athletes due to the fact that trained athletes appear to have improved response inhibition (fewer false clicks) during mental fatigue compared to their sedentary counterparts.

CHAPTER 1

INTRODUCTION

Exercise and physical activity, positively influence the brain with both cognitive and physiological benefits. Physiological benefits include an increase in neurotransmitter levels and more flow of oxygen and nutrients. Cognitive benefits include increases in ability to learn and memorize, gene expression associated with brain plasticity and neurogenesis enhancement, blood flow and neuronal resistance to injury (Ratey, 2011).

Exercise specifically affects the frontal cortex--the area in the brain that mediates cognitive processes. The nature of the frontal cortex allows humans to organize and coordinate brain functions that play a major role in human cognition. Problem solving, modifying behavior appropriate to environments, inhibiting previous responses, assisting in goal directed and self regulatory behavior are all functions of the frontal cortex. It composes a third of the human brain and is a structure that enables us to engage in higher cognitive functions that deal with planning and problem solving (Smith, 1999).

The prefrontal cortex (PFC) is the thick outer layer of the cerebral cortex of the prefrontal lobe (the front portion of the frontal lobe). The PFC is an integral part of person's personality and deals with personality expression, decision making and moderates social behavior. It is a widely accepted theory that the PFC stores short-term memory. There is agreement among the scientific community that these functions regulated by the PFC include attention and inhibition (Smith, 1999)

The most important function carried out by the PFC is executive function. Researchers suggest that regular aerobic exercise has potential to improve executive functioning in even healthy populations (Best, 2010). Executive function is responsible for regulation and control of cognitive processes and has two main sub levels. This includes lower level executive function and higher level cognitive function. Lower level consists of working memory cognitive flexibility and inhibitory control (such as response inhibition)

Executive functions are thought to be regulated by prefrontal regions of the frontal lobes. Both the frontal and non-frontal brain regions are necessary for executive functions. The dorsolateral PFC has been found to be associated with response inhibition, working memory, reasoning and problem solving.

Response inhibition refers to the elimination of actions that are inappropriate and that interfere with goal driven behavior. It ultimately plays a large role in executive functioning and is linked to impulsivity. Research to date has shown, the beneficial effects of exercise are present on both executive response and response inhibition. (Best, 2010) Exercise positively affects executive function as well higher cognitive processes may be affected

The present research study focuses on how moderate exercise affects response inhibition in trained athletes and non-athlete collegiate students. The effect of 35 minutes of moderate cycling will be examined on two groups of mixed sex, trained and sedentary individuals of typical collegiate age. This study is designed to show exercise will improve response inhibition in both groups. It is a key component of executive function and should therefore be affected positively. In a research study done to examine supporting links between regular aerobic exercise and specific components of executive functioning, cross sectional data indicated that aerobic fitness predicts better working memory (Machado, 2013).

I hypothesize that false clicks following the 5 minute CPT should decrease after exercising. Additionally, both subject groups' accuracy should be higher after moderate-intensity cycling. As a result of a difference in fitness levels, athletes should have a lower level of mental fatigue experienced throughout the CPT resulting in higher accuracy and lower false clicks compared to sedentary.

CHAPTER 2

LITERATURE REVIEW

Physical exercise is known to affect cognitive performance. Effects on this type of performance have been studied using a wide variety of tasks (finger taping task, stroop test, Simple RT tasks). Although there has been much research in this area, results relating to the impact of exercise on cognitive function have been inconsistent (Gates, 2013). These inconsistencies are possibly due to failure to distinguish between aerobic and non-aerobic activities, as well as failure to address duration, intensity and frequency of activities. This inconsistency emphasizes the need to highlight the effects of dose specific types of exercise on cognition (Tomporowski, 2003). Tomporowki et al. (2003) composed a review of studies that assessed physical activity on adult's cognitive performance. It concluded that sub- maximal aerobic exercise performed for periods up to 60 min facilitated specific aspects of information processing.

An emerging body of literature has concluded that aerobic exercise has beneficial effects on selective parts of the brain. Both human and animal studies have demonstrated that aerobic exercise has fundamental health promoting impacts. Its effects extend across vascular, metabolic, inflammatory and stress regulating pathways. Exercise has been shown to favorably affect the hippocampus memory systems (Cassilhas, 2011). It may also enhance memory through a brain region known as the amygdala. This region of the brain is involved in emotion, and activation of this area has been shown to regulate the hippocampus and enhance memory processing. Animal research has shown that when animals have access to exercise equipment (such as running wheels) that has a positive impact on neuronal growth and on the neuron systems that are a part of learning and memory (Reynolds, 2010). In human studies, recent advances in neuroimaging techniques have shown that exercise leads to changes in brain structure and function (Hillman, 2008). In the 1970's the first relationship with psychomotor speed and exercise was established. Older adults who exercised in comparison to older sedentary adults had much faster reaction times. At present, there is no study that documents if this relationship exists for younger adult (Sherwood, 1979).

Today there is a rising issue on how lack of exercise will effect children's brain performance and cognitive health overall Specifically in well-developed countries where obesity is becoming a main concern and children are becoming more unfit, little research has gone into determining the effects of physical activity on cognitive health during a child's development. There are only a handful of studies that use true experimental design that have contributed to our understanding in this area. In a study by (Sibley and Etnier, 2003), a positive relation was shown between physical activity and cognitive performance in school-aged children and measurements such as perceptual skills, intelligence quotient, achievement, verbal tests, mathematic tests, memory and developmental level/academic readiness. (Sibley and Etnier, 2003) Research efforts that have focused on the relationship between physical activity and academic performance have found no relationship between exercise and academic performance. However, these studies varied in protocols and how they measured scholastic aptitude.

A growing body of literature suggests that physical activity benefits brain function during young adulthood (Ratey, 2011). Specifically, it influences frontal lobe-mediated cognitive processes such as planning, scheduling, inhibition and working memory (Ratey, 2011). Throughout the beginning of human existence our hunter and gatherer ancestors had to be ready for periods of intense physical exercise and also rest. This was brought on by famine and ongoing search for food and land. In contrast, many modern day lifestyles do not call for physical activity and instead lead to a more sedentary lifestyle. It has only recently been suggested that physical activity also has the benefit of enhancing cognitive performance. With that said, if society as a whole is leading a more sedentary lifestyle our cognitive abilities are bound to be effected in numerous ways.

There is a scarcity of research that exists on exercise cognition effects in young adults. Exceptions do exist, and this research is primarily focused on acute exercise effects on cognition (Ratey, 2011). Most research has used younger adults merely as a comparison with older adults to try and gain insight on physical activity on cognitive aging. There is a small body of literature that examines neurophysiological indices of cognitive function and the benefits of regular physical activity in young adults. Future research focusing on young adults, should emphasize understanding the mechanisms of exercise on the brain as well as applied aspect of cognition related to school and work performances (Hillman, 2008).

Neurophysiological studies have revealed differences in cognitive function and how they are related to our physical activity behavior (Hillman, 2011). Magnetic Resonance Imaging (MRI) is one of the many techniques that have been used to examine the effects of exercise on the human brain. In a study that compared individuals with high and low levels of fitness, it was found that higher levels of fitness improvements were associated with a larger volume of prefrontal and temporal grey matter that was seen in individuals who exercised on a consistent basis. This increase in brain volume is predictive of performance in older adults (Hillman, 2011).

Although MRI is very useful, there are limitations to the extent to which we can study the human brain through imaging. In contrast, animal research in this area can examine the cellular and molecular cascades that exercise trigger. We aren't able to comprehensively analyze humans on a cellular level simply due to vast complexity of the human nervous system. What has been found in animal testing is that there is an increase in cell proliferation and cell survival in the dentate gyrus of the hippocampus(area of the brain where neurons grow the fastest in rats). The relationship exists in both young adulthood and old age. These proliferated cells may be the catalyst to better learning and memory.

Dating back to 1959, there have been papers that have been published in regards to the effects of physical exercise on cognitive performance (Hamilton, 1959). Many of them up until the twenty first century, have highlighted the negative effects of exercise on cognitive ability. During the mid-twentieth century, controversies over the relationship between the two existed.

In 1973 a review article, *Exercise-Induced Activation and human Performance* written by Bernard Gutin, proposed a theory for exercise-induced changes in activation (EIA) and performance of various motor and cognitive tasks. The result of Gutin's research concluded that levels of performance were optimal when there were intermediate levels of exercise-induced changes in activation. In contrast, tasks that required a large deal of steadiness (inhibition) have highest levels of efficiency at lower levels of EIA. For intellectual tasks, intensity of exercise is negatively related to cognitive performance (Gutin, 1973).

In 1986, Hancock completed a research study in which six subjects completed a research study that measured the maximum Vo2 levels before taking two visual perception tests. The two tests were taken when the subject was either rested or fatigued (Hancock,1986) . The definition of fatigue in this context was when the subject was working at or above their anaerobic threshold. Both tests for the different states were similar. Statistical analyses revealed a significant difference between the fatigue and rest scores ($p < .05$). That data suggested that under the influence of fatigue the subject's ability to perceive the visual information displayed was significantly decreased. The authors also state that there was a positive but not statistically significant difference in attention and map interpretation while fatigued. Under fatigue, estimation abilities and short term memory tended to be better. However this was not statistically significant. The subjects ability to immediately recall information in the fatigued state, showed a positive increase. It was suggested that "this occurrence could be due to heightened level or arousal brought by exertion". This could also be caused by the narrowing of attentional focus, which would essentially make the subjects perception be more acute. In contrast, the performance of the subjects was worse when they were in a state of exhaustion, compared to when they performed the test under conditions when they were well rested. The subject's ability to interpret symbols and certain features became worse when they were tired.

Mental fatigue has been associated with impaired cognitive and behavioral performance (Boksem, 2008). Boskem's study shows that subjects had difficulties adequately preparing their responses to assigned tasks. Also these subjects had difficulty paying attention and ignoring distractions. Mental exertion can be evaluated by performing mental tasks. If it is prolonged it may exhibit mental fatigue, which may effect cognitive performance. Mental fatigue refers to the feeling that people may experience after or during extensive periods of cognitive activity. These feelings may lead to a decrease in the amount of commitment to a given task, which in turn is related to response inhibition.

Despite the claims that exercise did not positively affect results, it was theorized that executive function would be affected by exercise. (Hillman, 2003) concluded that tasks that require reasoning and effort, such as executive control process are affected by neuroelectric processes underlying executive control through increased appropriation of neuroelectric resources and increased processing demands. Since physical activity has been found to enhance cognition and with a larger effect on executive control function, it can be assumed that brain structures that mediate executive function would show some change as a result of exercise (Hillman, 2008).

In 2009 it was analyzed that the time course effect (effect over time) of moderate steady state exercise on response execution and response inhibition. The results signify that the beneficial effect of exercise is neither limited to motor response tasks nor to cognitive tasks performed during exercise (Joyce, 2009). These results show that certain cognitive processes are affected differently by acute exercise (short lived exercise that is less intense). Most importantly, studies show that acute exercise affects certain aspects of cognitive function differently (Davranche, 2008). Based on the present findings of this research it can be concluded that cognitive processes are affected differently by exercise.

Some of these processes are impaired while others are positively affected or not altered. For example, it is known that acute moderate exercise enhances cognitive function. This is due to an improvement in peripheral motor senses.

The effects of exercise on basic cognitive processes is well documented. However the effect on higher cognitive processes are not well understood. The basis of higher level executive function/ cognitive processes relates to factors such as inhibition, flexibility of thinking, problem solving, planning, impulse control, concept formation, abstract thinking and creativity. There is research that states that there is a deteriorating effect on response inhibition after moderate exercise (Davranche, 2009).

Response inhibition is a cognitive process that is affected by exercise. It refers to the inhibition of unwanted motor or emotional responses (Mostofsky and Simmonds, 2008). It is responsible for the main component of decision making. Tasks that require you to use response inhibition, activate the pre-supplementary motor area and the anterior cingulate cortex (ACC). The Stroop task is a test that activates this area of the brain. Activity in the area has also been linked with perception and effort. Therefore, it is plausible that prior mental exertion involving response inhibition would therefore affect effort-based decision making processes that regulate self-paced endurance performance (Pageaux, 2013).

The study I will be conducting will examine how trained athletes and non-trained athletes are affected by a cognitive performance test that induces mental fatigue. I will be specifically looking at how the two groups' response inhibitions are affected (mean false clicks based on the CPT). Studies relating to this area have been highly inconsistent and little research has been done comparing college-age athletes vs. non-athletes. I will help close this gap and identify a direct relationship between cognitive performance and mental fatigue.

CHAPTER 3

METHODS

Participants

Participants were six young adults (3 females, age range 20-23 years, 22 ± 1.0 ‘; year) and (3 Males, age range 20-23, 22 ± 0.6 years). These young adults were college students who volunteered from the Georgia Institute of Technology. Participants were not compensated. All subjects provided written informed consent as approved by the Institutional Review Board.

Two groups of subjects (three in each group) were recruited in this study. One group was made up of NCAA Division I Georgia Tech Cross Country and Track Athletes. The other group was made up of individuals considered sedentary in comparison to the other group. Sedentary individuals were physically active but not regularly engaged in endurance running (averaging no more than 15-20 minutes of running once to twice per week). In comparison, the Athletic subjects averaged at least an hour of endurance running no less than five times per week.

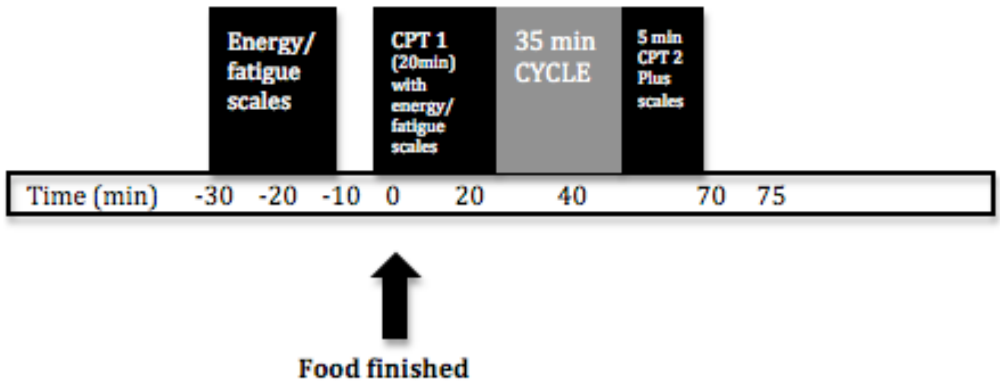


Figure 1. This is the protocol that was used for exercise.

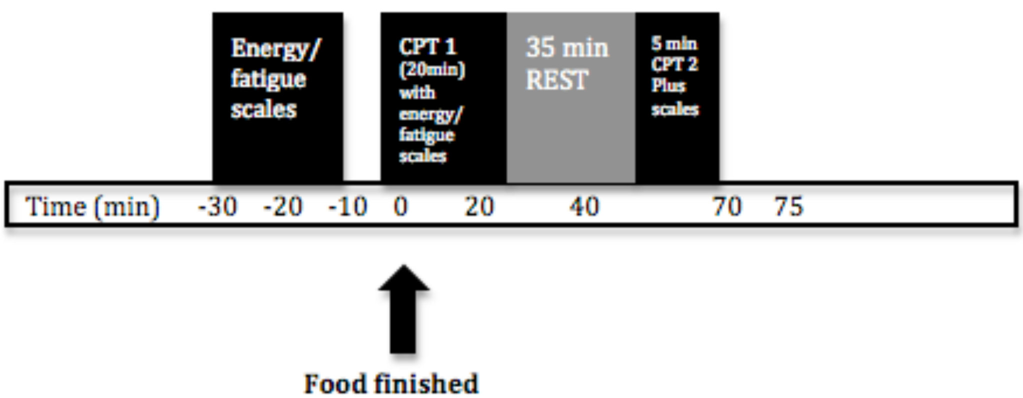


Figure 2. This is the protocol that was used for rest.

The experiment used a within-subject, counterbalanced design with subjects serving as their own control in completing conditions (rest and exercise following mental fatigue). The test protocol involved two testing conditions (illustrated in Figure 1 and 2). Subjects came in the morning from 6:45 AM to 9:30 AM during each test condition after an overnight fast. The second test was done within two days, with the exception of subject 6. Due to illness, subject 6 was scheduled a week following the first test.

When subjects first arrived, they filled out forms, which consisted of a 24 hour history report, Profile of Mood States (POMS) (Terry, 2003) and visual analogue scale (VAS) (Krabbe, 2006). The 24 hour history measured variables such as sleep, caffeine and other substances that could possibly have an effect on the results of the data. POMS is a questionnaire that consists of 65 adjectives that are rated by a subject on a five point scale to assess mood states. There were six factors analyzed: tension-anxiety, depression-dejection, anger-hostility, fatigue-inertia, vigor-activity, confusion-bewilderment. Of the six factors, two were of primary importance: fatigue-inertia and vigor-activity.

The Visual Analog Scale (VAS) is a psychometric response scale that is a 10 cm anchor with 2 extreme poles. There are word descriptors at each end and the subject marks on the line the point that they feel represents their perception of their current state. From this form, mental energy and fatigue along with physical energy and fatigue is measured for the subject in their current state of mood (See Appendix).

There were a total of three specific forms used for the study. Two (POMS and VAS) were used a total of three different times. Another form was used to record heart rate (HR), ratings of perceived exertion (RPE), revolutions per minute (RPM) and watts of the subject used during cycling. The group of forms were given when the subject first arrived at the laboratory, after the twenty minute CPT and after the final five minute CPT. Once the forms were completed for the first time point, a standardized chewy granola bar and 400 ml bottle of a flavored non-calorie drink (no caffeine or carbohydrate) was given to the subject. Once the subject had finished the bar and beverage, they were directed to the computer where they began the first 20 minute Continuous Performance Test/Task (CPT). The length of the test was 20 minutes in order to simulate mental fatigue experienced during a normal day.

Once the CPT was completed the subject filled out another set of forms to evaluate their mood at the current state. Once forms were completed, participants began exercise or rest protocol dependent on athletic or sedentary group. Student athletes had the resting protocol first while sedentary students had the cycling protocol first.

The cycling protocol consisted of a five-minute warm up at 50 watts. Prior to mounting the bike, a heart rate monitor was placed on the subject and the initial heart rate was taken. The bicycle ergometer (Load Excalibur Sport, Groningen, Netherlands) was a stationary bike with adjustable seat and handle bars. In order for a moderate exercise level to be achieved, the subject rated their level of exercise effort using The Borg Scale of perceived exertion (Borg, 1982). The Borg scale matches subject's effort with numbers ranging from 6 through 20. It is a relative scale that allowed the subject to self-select how hard they are working. The scale started at a 6, which signified "no feeling of exertion" and went up to a 20 which signified maximum effort. Moderate exercise began at the level 11 and stopped at 14. For this experiment the subjects were requested to exercise at an intensity equivalent to level 12 (65% effort) "Moderate intensity steady-state aerobic exercise (lasting less than 60 minutes in duration) has been shown to provide evidence of positive effects of exercise on attentional processes, creativity, stimulus detection and coincidence-timing tasks." (Tomporowsk,i 2008). By allowing subjects to self-select their level of effort, this simulated the same level of effort based on fitness status of the subject.

When the subjects completed the resting protocol they sat in a very comfortable chair for 35 minutes. They could relax while sitting and there were no limitation of what they could do while resting. Many subjects looked at their phones while a few read for short periods of time and others slept. After the subjects completed 35 minutes of either resting or cycling they completed the final 5 minute CPT. The subject filled out the last set of forms before leaving. For the next trial, each group of subjects completed the second protocol depending on which was done previously.

Continuous Performance Test

The Continuous Performance Task/Test (CPT) is a computerized assessment of a task based on attention related problems. The test required use of working memory, response inhibition, and error tracking. The CPT is now cited as the most frequently used measure of attention in both practice and research (Riccio, 2002). Importantly it is associated with the anterior cingulate cortex (ACC). The ACC detects conditions under which errors are likely to occur rather than errors themselves. Furthermore, the ACC is affected by mental fatigue and may impair performance in subsequent physical tasks (Marcora, 2009). During the CPT, a series of letters are displayed on a computer screen (centered at the mid top). Subjects were told to click in a white box whenever the letter T was shown. The letters on the screen were precisely 1.5 inches in height, had a color of white and were capitalized. The letters were all shown on a black background. The rate at which the letters appeared was 1.5 letters per second. There were a total of 2000 letters for the entire length of the CPT (20 minutes).

The data collected from the CPT was total false clicks and accuracy. Total false clicks are variables outputted by the CPT. Total False clicks are the number of times a subject clicks when the letter 'T' is not displayed. Accuracy was calculated by correct clicks/ total clicks. Other variables obtained from the CPT are true positives (TP) or correct hits, true negatives (TN) or correct misses, false positives (FP) or false clicks, and false negatives (FN) or missed targets.

Statistical analysis

The data has been reported as the means and standard error and was analyzed using SPSS version 17.0 (SPSS 2007). Using a GLM univariate repeated measures ANOVA with between factor group and within factor time with repeated measures with between factor group and within factor time. Trial and time were analyzed as main effect factors and level of fitness was analyzed as between-subject factors. Time*Trial was analyzed as an interaction effect. These measures were analyzed over time to access differences in false clicks and accuracy. The Greenhouse-Geisser correction factor was used in order to account for sphericity assumption of unequal variances across groups. A Bonferroni post hoc test was used to distinguish significant differences between means. Statistical significance was set at an alpha of $p<0.05$. The dependent variables were the first total correct clicks in 5 minutes at time point 1 (baseline), the total correct click in the last 5 minutes of the 20 min CPT(time point 2), and the total correct clicks in 5 minutes of time point 3 (following the 35 min rest or exercise conditions). These time points were analyzed across both conditions (rest and exercise) for all subjects (sedentary and trained).

CHAPTER 4

RESULTS

The primary dependent variables: Response Inhibition (false clicks) and Accuracy (% correct) were measured across three different time points:1) time point 1/Baseline (first five minutes of the 20 minute CPT), 2) time point 2/Post CPT (the last five minutes of the 20 minute CPT) and 3) time point 3/Post Condition (the five minute CPT after the resting/ cycling protocol). The dependent variables were also analyzed by conditions (rest and exercise) and by subject group (sedentary vs. trained).

False clicks were recorded as mistakes made throughout the CPT. Referring to the overall trend in data presented in Figure 3, there was a significant overall effect of time ($p=0.008$). The representation for mean and standard error will be as following (mean± SE). False clicks increased significantly from baseline (time point 1) (12.2 ± 2.6) to after the 20 minute CPT (time point 2) across both rest and exercise conditions (24.3 ± 4.3). This increase in average false clicks was anticipated because it is a marker of mental fatigue (reduced sustained attention) which is known to occur over the 20 min of a CPT. As indicated in figure 3, time point 3 is lower compared to time point 2. The mean false clicks at time point 3 were 10.6 ± 2.5 (across both conditions) and for time point 1 they were 12.2 ± 2.3. This is an indication of “recovery” from mental fatigue.

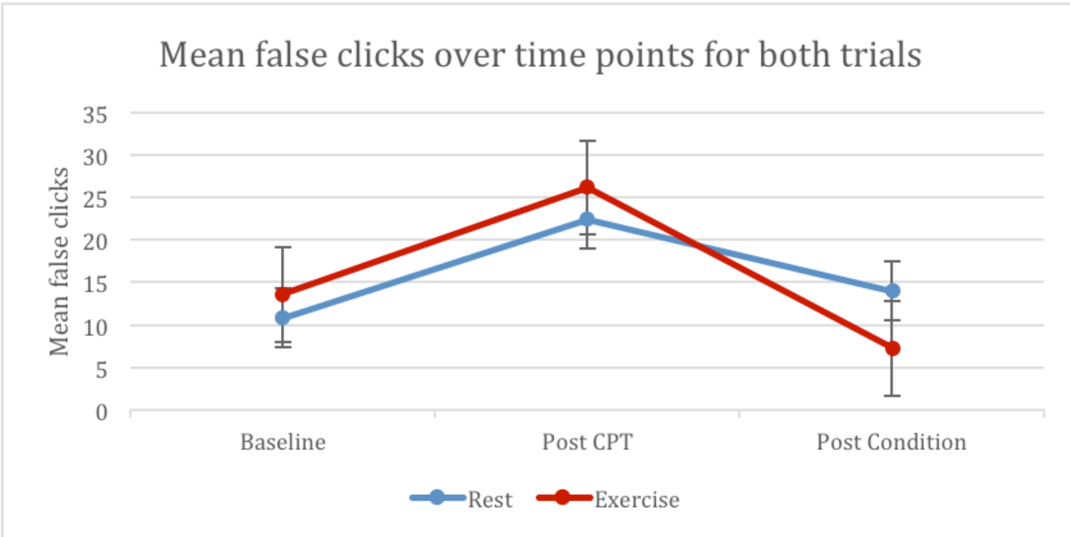


Figure 3. Mean (± SE) false clicks over time points for rest and exercise conditions.

The effect of rest versus exercise condition over time is presented in Figure 3. It was anticipated that time point 1 and time point 2 would be similar between the conditions (rest vs. exercise) because these time points were prior to the experimental condition which was implemented 35 min following mental fatigue (20 min CPT). There was no significant net difference between time point 1 and time point 2 over the rest and exercise conditions. The mean false clicks for time point 1 was similar for rest (10.7 ±2.9) and exercise (13.5 ± 3.3). For time point 2, mean false clicks also increased in a similar fashion after the 20 min CPT prior to the rest 22.5 ± 5.7 and exercise condition 26.1± 3.9. However, the difference in average false clicks between conditions (rest vs. exercise) at time point 3 was greater for rest (14.0 ± 3.6) compared to exercise (5.5 ± 1.1). This difference was significant (p=.049) (obtained from post hoc tests) , suggesting that there was an interaction effect and that exercise will help restore subjects' ability to perform to better than rest (shown in Figure 4 below) . To examine the time by condition interaction, additional post hoc tests revealed a difference. The overall p value was .942 when looking at the variable Trial. Moderate intensity cycling for 35 minutes significantly improved (p =.008) by scores compared to time point 2 of mental fatigue (19.0 ± 3.4 and 6.3 ± 2.7 respectively). However, when subjects rested for 35 minutes after experiencing mental fatigue, they performed similarly to time point 2.

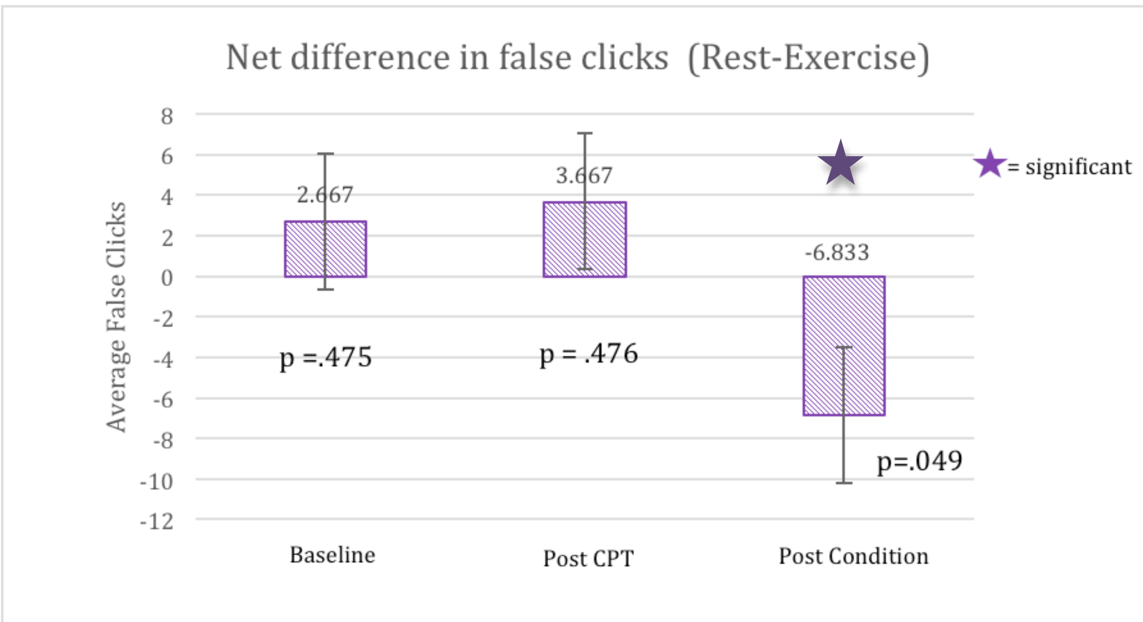


Figure 4. Mean (± SE) difference in false clicks at baseline, after the CPT and after rest versus Exercise * significant difference for the condition effect.

When analyzing between-subject differences in sedentary vs trained subjects, no significant differences were found (p = .095). However, due to the limited sample size (only 3 subjects per group), this data has practical significance to indicate a trend. With a small sample size, there is a low statistical power and hence with more subjects it is possible that a significant p value may be obtained.

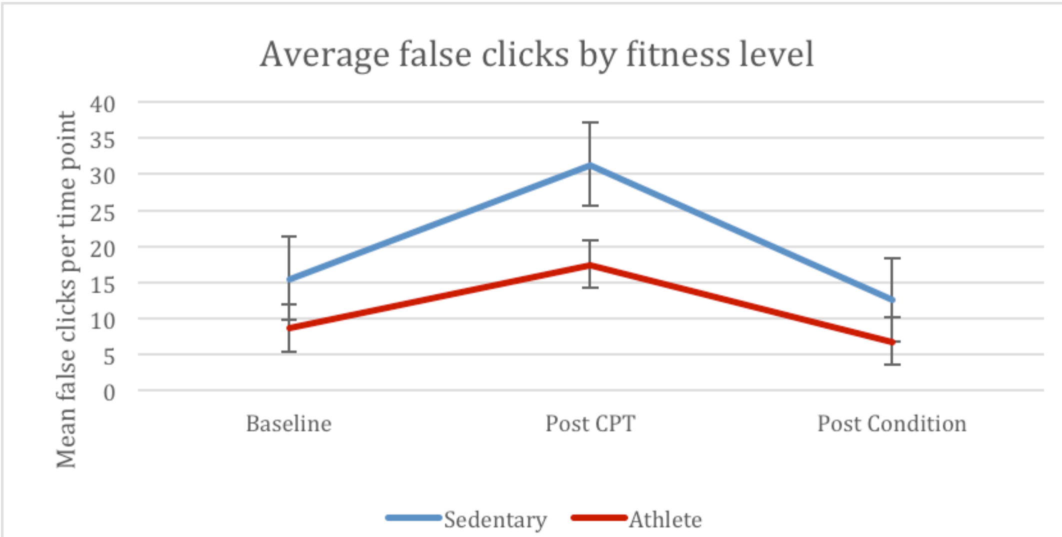


Figure 5. Mean (±SE) average false clicks by fitness level.

Figure 5 illustrates the overall influence of fitness status on response inhibition (p =0.095). At baseline (averaged across both test conditions), the trained group tended to have fewer false clicks (p=.203) than sedentary subjects (8.7 ± 8.6 for trained and 15.5 ± 4.3 for sedentary, respectively). Athletes during both conditions tended to have fewer average false clicks (11.0 ± 3.3) across all time points compared to sedentary subjects (19.6 ± 5.8) . Overall for baseline, athletes had a 56.1% lower false clicks compared to sedentary subjects. This was unexpected since this difference at baseline occurred prior to the experimental condition.

For time point 2, athletes also tended to have fewer(17.5 ± 2.8) false clicks on average compared to sedentary subjects (31.1± 4.8) . Overall for time point 2, athletes had 57.6% lower false clicks (p=0.104) compared to sedentary subjects. Compared to baseline, athletes at time point 2 there was a 50% increase in false clicks on average. Compared to baseline, sedentary subjects increased false clicks at time point 2 by 49.5% clicks on average. This trend continued after 35 minutes of rest (19.3 ± 5.7) or exercise (6

± 2), p=.140. Thus, it appears that trained athletes tended towards less mental fatigue during the CPT which persisted during the recovery (averaged across both the rest and exercise post-CPT conditions).

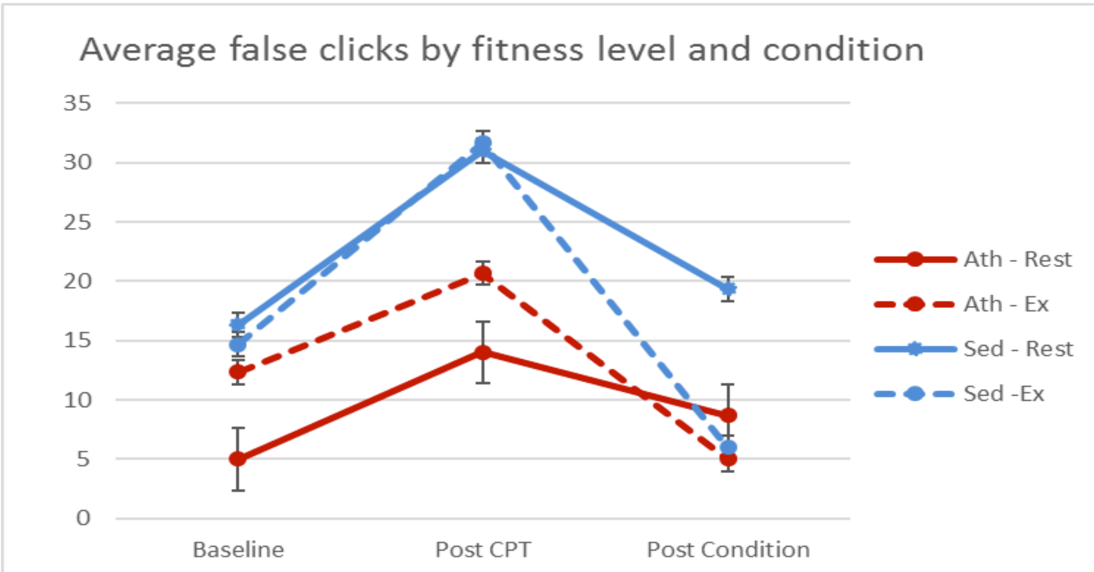


Figure 6. Average false clicks by fitness level and condition

Figure 6 depicts average false clicks for fitness group by condition (following rest vs. exercise) over time. Sedentary subjects were not different (p=.669) during rest or exercise conditions at baseline (time point 1) or after 20 minute CPT (p=.931 sedentary) (p=.408 athletes) (time point 2). In comparison, athletes exhibited a tendency for a lower baseline score in the rest condition (p=0.167) compared to sedentary. However, there was a significant difference in the effect of exercise by group. For sedentary at time point 3, false clicks were lowered significantly (p=0.047) by exercise (6.0 ± 1.2) compared to the rest condition (19.3 ± 3.3). The trained group did not significantly differ (p=.356) at time point 3 for rest, having 8.7 ± 4.9 false clicks and 5.0 ± 2.1 false clicks after exercise. Therefore, it appeared that most of the exercise benefit was observed due to the improvement in the sedentary group.

Accuracy is recorded as the % of correct clicks out of total clicks (100% as a perfect score) made throughout the CPT. Referring to figure 7, there was an overall effect of time (p=.006). Accuracy decreased significantly from baseline (time point 1) (91.4% ± 1.9%) to after the 20 minute CPT (time point 2) across both rest (82.3% ± 4.4%) and exercise conditions (80.3% ± 3.5%). This decrease in average accuracy (by 9.8%) was anticipated because it is a marker of mental fatigue (reduced sustained attention), which is known to occur over the 20 min of a CPT. Furthermore, since false clicks also significantly increased at this point, this contributed to the reduced accuracy. As indicated in figure 7, time point 3 for exercise (94.0% ± 2.0%) is not significantly higher compared to time point 2 (80.8% ± 3.5%). Accuracy at time point 3 (across both conditions), was similar to baseline (time point 1) (91.5% ± 2.1%). This again is an indication of a mental "recovery."

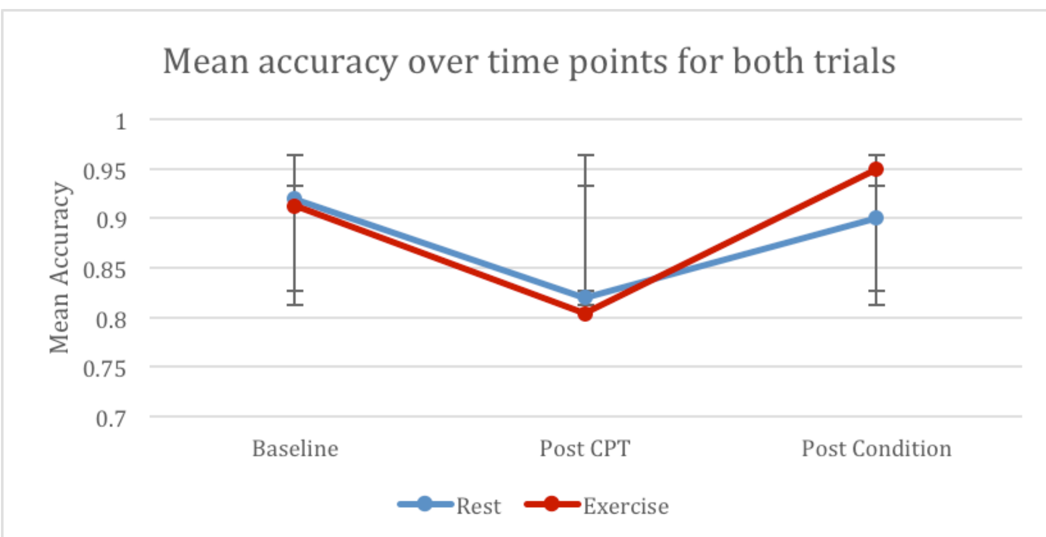


Figure 7. Mean (±SE) accuracy over time points for both trials (rest or exercise).

The effect of rest versus exercise condition over time on mean accuracy is presented in figure 7. It was anticipated that time points 1 and 2 would be similar between the conditions (rest vs. exercise) because these time points were prior to the experimental treatment which was implemented 35 min following mental fatigue (20 min CPT). There was no significant overall effect for Rest vs. Exercise Condition ($p=0.624$) or time x condition interaction ($p=0.259$), but there was a significant time effect ($p=0.047$) with a decrease of 9.8% accuracy between baseline and post-CPT and then and increase back to 92.6% after rest and exercise combined. There were no significant difference at time point 3 after rest ($p= 0.098$) and exercise ($p=.811$) conditions.

The mean ± SE difference in accuracy between rest and exercise conditions for time points 1 and 2 were 0.5% ± 1.8% ($p=.79$) and 1.5% ± 3.9% ($p =.74$), respectively. The difference between conditions (rest vs. exercise) at time point 3 was higher (4.6%± 2.0%), but non-significant ($p =.098$). Analyzing time point 3 for the rest condition, accuracy was 90.3% compared to a baseline of 91.7% .When subjects rested for 35 minutes after experiencing mental fatigue, they tended to perform on average worse on the CPT compared to baseline (“incomplete recovery”). However, for the exercise condition at time point 3, accuracy was 94.9% compared to a baseline accuracy of 91.1%. Exercise was able to restore and improve subject’s baseline accuracy.

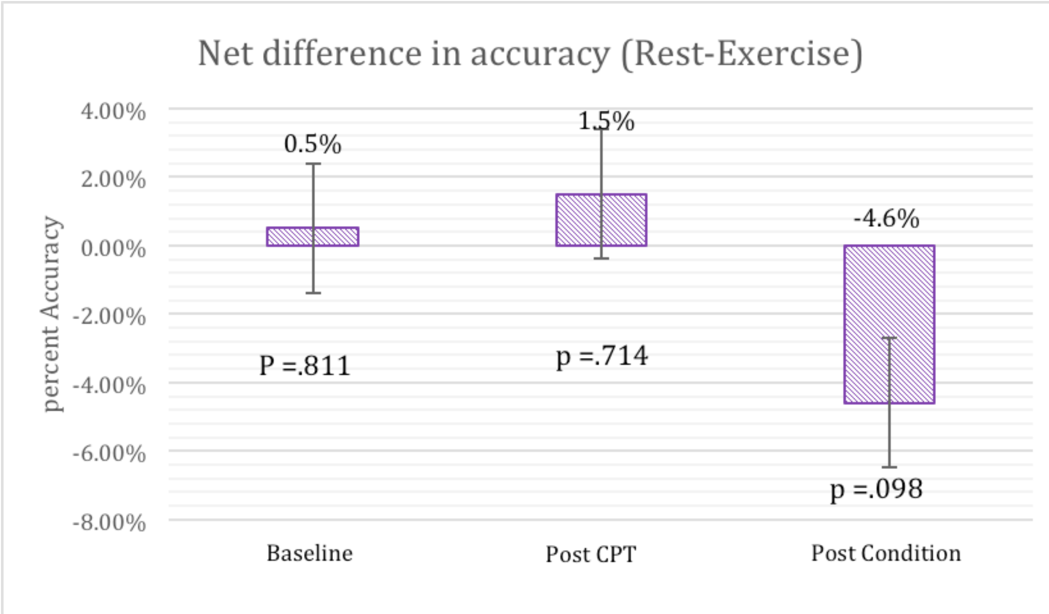


Figure 8. Mean (±SE) average accuracy based on subject's fitness level averaged across the two conditions (rest or exercise) * there is -4.6% larger accuracy score for exercise compared to rest

Figure 9 presents the effects of fitness status (sedentary compared to trained groups) on average accuracy. Overall, fitness status did not significantly influence accuracy over all time points for test of between subject effects (p= .052). However, the data indicated a trend for the athletes to have greater accuracy across the time points. With a low sample size, there is a low statistical power. Increasing the sample size could potentially result in a significant p value.

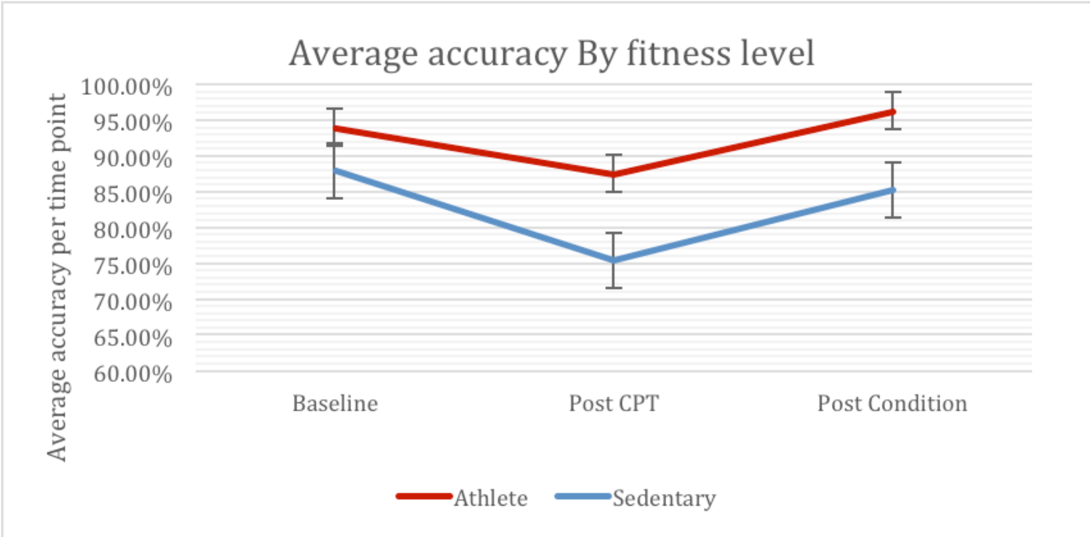


Figure 9. Mean (±SE) accuracy for each time point. Accuracy was measured for rest and exercise trials for athletes and sedentary subjects.

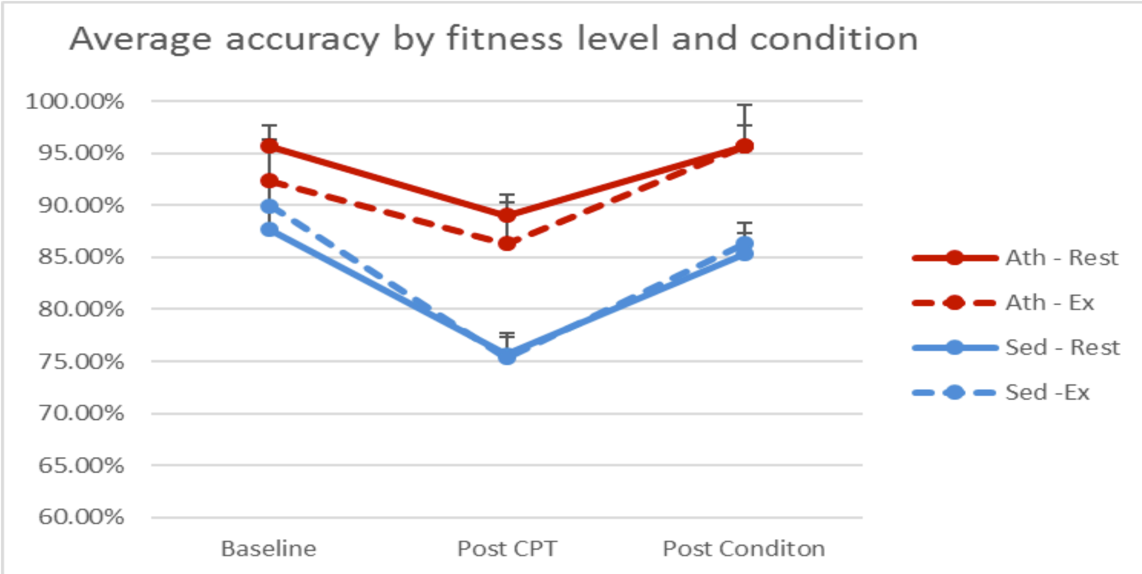


Figure 10. Mean (±SE) accuracy for each time point. Accuracy was measured for rest and exercise trials for athletes and sedentary subjects.

Figure 10 depicts average accuracy for each fitness group by condition over time. Sedentary subjects and athletes were not different during rest and exercise (87.6% ± 2.0% Sedentary 95.6% ± 1.4% Athlete) at baseline or after the 20 minute CPT (89.9% ± 2.1% Sedentary 92.3% ± 4.1% Athlete). Athletes exhibited a tendency for a higher baseline score in the rest condition (p=.262) versus their exercise baseline condition. For sedentary at time point 3, exercise tended to increase accuracy (p=.062) (86.0% ± 3.0%) compared to rest (84.3% ± 3.5%). The athlete group did not significantly differ at time point 3 for rest (95.6% ± 2.3%) versus exercise (97.0% ± 1.8%) (p=.597). Therefore, it appeared based on a non-significant trend in the data that more benefit of exercise was due to the improvement in accuracy in the sedentary group.

CHAPTER 5

DISCUSSION

It was hypothesized that response inhibition would be positively effected by exercise. Overall it was found that thirty-five minutes of exercise can help restore a persons cognitive ability and actually improve scores based on the CPT. It was found overall that subjects ability to perform after exercise was up to 14.0% better in terms of false clicks and 4.0 % better in terms of accuracy. The implications of this study further suggest exercise has a beneficial impact on academic achievement and cognitive ability.

Based on current research, acute exercise appears to have a positive impact in subject's ability to perform mental tasks that require higher-order executive function. It has been concluded that sub maximal aerobic exercise performed for periods of up to 60 minutes facilitate specific facets of information processing (Tomporowski, 2008). However extended exercise that leads to dehydration causes high arousal levels and compromise information processing and memory functioning (Tomporowski, 2003). A model relating performance to stress or autonomic arousal is the "catastrophe curve" (Hardy 1989). This model states that under low levels of stress and physiological arousal individuals improve in performance as these two factors increase. However when there is an imbalance between the task at hand and his/her capability to match them, anxiety occurs and performance deteriorates rapidly.

The acute exercise performed in the two protocols of this experiment did not allow for a significant amount of dehydration that might influence CPT results. Exercise was below 60 minutes and was of moderate intensity in a cool environment. A fan was placed in front of subjects to make sure they were cool. Subjects were not visibly sweating during the exercise. Under these conditions, moderate exercise could positively affect executive performance.

Based on figure 3, as expected, exercise positively affected how subjects performed. Subjects were able to perform better than baseline (scoring fewer false clicks on average) after exercising aerobically for 35 minutes. Exercise included 35 minutes of moderate cycling where subjects self-selected their pace according to Borg's Rating of Perceived Exertion Scale. Subjects on average, exercised at a "somewhat hard" level of 12. Moderate intensity cycling for 35 minutes significantly improved ($p=.008$) scores by (19.0 ± 3.4) less false clicks.

Compared to figure 3 (Mean False Clicks over time points for both trials), accuracy shows a similar trend but reversed (figure 7). As expected, both sedentary and athletic subjects started at the same baseline and decreased in accuracy in a similar pattern. The main difference occurred at time point 3 where as a result of exercise, accuracy increased. Again, the difference at time point 3 was not statistically significant ($p=.090$) However, for the exercise condition at time point 3, accuracy was nearly 4.0% better compared to baseline accuracy. Most students would agree that a 4.0 % better score on an exam is a practically relevant finding.

A popular focus of sports psychology has been the preparation of mental skill training (MST). There is a certain quality of mental training that all athletes most endure in order to get to their optimum level of performance. There have been experimental studies that show MST to be effective in implementing a greater mental skill in athletes in any range of sports. (Sheard and Golby, 2006). (Krane and Williams, 2006) concluded that a number of common mental characteristics already exist for peak performance.

These are the mental skill of self regulating peak arousal, having high self confidence and thoughts of success, feeling in control of all situations including yourself, focusing on the present task, viewing difficult situations as challenging and exciting, positive attitudes and cognitions about performance.

The longest standing graphical model describing the relationship between stress, anxiety and performance in sports is the inverted-U hypothesis (Yerkes and Dodson, 1908). This predicts that performance improves with an increase in arousal until a peak is reached. After the peak is obtained further arousal causes a decline in performance. This hypothesis is linked to the drive theory (Hull, 1943) in which it can be determined the performance is positively related to arousal. Two theories can be obtained from this model. The first being, increased arousal allows the mind to perform better. The second being if one becomes too highly aroused, cognitive performance declines. These two analyses can be used to support results in which sedentary subjects benefited more from exercise in comparison to the athletic group. Sedentary subjects may have been in the optimum zone of the inverted U and were therefore able to improve more drastically (Ivan McNallly, 2015).

In reference to figure 3, the values at baseline are not the same and this difference in value could possibly be explained by an effect of fitness levels. Elite athletes (Division one athletes of Georgia Institute of Technology) follow MST on a regular basis. Athlete's constant use of MST is at minimum, partially the reason for lower false clicks and higher accuracy through each time point.

Athletes experience constant mental toughness due to exercising on a regular basis. Mental toughness is defined as "the maintenance of one's own optimal mental qualities in the face of adversity and pressure. It also deals with regulation of attentional focus" (Holland, 2006). My Hypothesis is that athletes are more susceptible to improving their cognitive ability on a more consistent basis because of the constant use of MST. Therefore athletes have a higher baseline to begin with, because of how much more they are exposed to this way of thinking compared to sedentary individuals. Baseline values may also have been different depending on what trial was first (i.e. a learning effect). Based on figures 6 and 10, there seems to be no current order effect. Athletes actually performed better (lower false clicks and higher accuracy) on their first trial baseline. Sedentary subjects seemed to perform better on their second trial baseline (lower false clicks and higher accuracy). A true counter balanced design or an initial orientation to the procedure prior to data collection, could have controlled for any learning effects in the groups.

Looking at time point 2 for figure 5, the number of false clicks for athletes doesn't increase as much compared to sedentary subjects. This again, could be due to the fact that athletes have more mental toughness. Furthermore it could be in reference to the inverted U hypothesis in which sedentary subjects were in the optimum zone and were therefore able to reach peak performances. Out of the three sedentary subjects, only one participated in high school cross country (the length of participation is unknown). All athletes participated throughout 4 years of high school in cross-country and track. The group of students that went on to compete at a division one level should have a higher level of Mental Toughness and optimized MST. Multiple variables, such as explained previously should be considered. The psychological mindset of athletes and sedentary individuals should be taken into account when optimizing a cross sectional design. This is a "weakness" that is inherent in cross sectional design.

It is apparent in figure 5 at time point 3 (last group of 4) athletes did not improve nearly as much in false clicks compared to sedentary subjects. I hypothesize this is because athletes already begin at a higher baseline and already went past peak levels in the Inverted U. Sedentary subjects however have much more potential for short-term benefits of exercise because of their lower fitness level.

Looking at figure 9, the trend is similar to figure 4. Subjects who exercise on a very consistent basis (Athletes) have higher accuracy overall throughout each specific time point. Although the p value was non significant at .062 for time point 3 for sedentary group, this value is close to significance with a sample size of 3. Based on the data, the most benefit of exercise for accuracy appears to be for the more sedentary subjects.

For further explanation of fitness levels effect on results, an experiment could be performed in which all subjects studied are classified initially as "unfit." The CPT would still be used in the same manner to access the individuals. However, those same individuals would then partake in a training regimen (of unknown length) in which they became "fit". Results could possibly show a better understanding of the direct impact that fitness level has on cognition as a whole. This type of study would implement a longitudinal experimental research design, which is stronger to determine "cause and effect" compared to the cross-sectional design used in the present study.

Overall the hypothesis of this study was supported by the results of this experiment. Response inhibition is positively affected by moderate exercise. Moderate cycling for 35 minutes helps reduce false clicks made on the post treatment CPT. Not only did false clicks decrease but accuracy increased as a result. For future experimentation, a proper counter balanced design can be implemented to the experiment. For this study, subjects were classified (as sedentary or athlete) and based on this information assigned to exercise or rest condition first. It did not appear that the effects of the design of this experiment caused any sort of order bias for the athlete group through out the experiment. However a learning effect may be the explanation for sedentary subjects performing better on trial 2 at baseline.

Due to a small overall sample size (n=6) as well as groups based on fitness (n=3), statistical power was likely low, making it more difficult to obtain statistical significance ($p<0.05$). Yet, a significant effect for exercise $p = .049$ (at time point 3 for mean false clicks) was obtained, suggesting that exercise will help restore subjects performance to better than rest. With a greater sample size, more significant p values may have been achieved to understand the chronic effect of fitness on ability to resist mental fatigue (i.e. response inhibition and maintain accuracy). The concept that fit individuals have great endurance capacity (physical and mental) is supported and similar to that reported previously (Holland, 2006).

The implications of this study are that moderate exercise does have beneficial impacts specifically on cognitive performance and that exercise should be incorporated more so into the daily routines of all people. Research has shown that school children that participate in 60 minutes of daily physical activity perform better academically. It has been reported that participating in physical activity was positively related to outcomes including academic achievement, academic behaviors, and indicators of cognitive skills and attitudes pertaining to concentration memory and self esteem (Rasberry, 2011). The direct effect of fitness level on cognitive performance is still uncertain amongst the scientific community. The effect of fitness on this study was insignificant, although it is possible that with a larger sample size significance could have been achieved.

APPENDIX A

METHODS TABLES AND FIGURES

Figure 11. This is the Visual analogue scale that was used for documentation.

Name:____________________ Trial #______ Beverage #_________ Pre____ Post____

Date:____________________

This part of the questionnaire asks about your current feelings of energy and fatigue. We are interested in how you feel right now, even if it is different than how you usually feel. Therefore, it is important that you focus on how you feel right now at this moment in responding to each item. There are no right or wrong answers. Please be as honest and accurate as possible in your responses. Make a vertical line through each horizontal line below to indicate the intensity of your current feelings. If you have a complete absence of the feeling described then place a vertical mark at the left edge of the horizontal line. If your feelings are the strongest intensity that you have ever experienced then place a vertical mark at the right edge of the horizontal line. If your feelings are between these two extremes, then use the distance from the left edge to represent the intensity of your feelings.

Example:

I feel I have no energy — Strongest feelings of energy ever felt

How do you feel right now with regard to your capacity to perform your typical PHYSICAL ACTIVITIES

I feel I have no energy — Strongest feelings of energy ever felt

I feel no fatigue — Strongest feelings of fatigue ever felt

I feel I have no vigor — Strongest feelings of vigor ever felt

I feel no exhaustion — Strongest feelings of exhaustion ever felt

I feel I have no pep — Strongest feelings of pep ever felt

I have no feelings of being worn out — Strongest feelings of being worn out

Name:______________________ Trial #_______ Beverage #__________ Pre_____ Post_____
Date:______________________

This part of the questionnaire asks about your current feelings of energy and fatigue. We are interested in how you feel right now, even if it is different than how you usually feel. Therefore, it is important that you focus on how you feel right now at this moment in responding to each item. There are no right or wrong answers. Please be as honest and accurate as possible in your responses. Make a vertical line through each horizontal line below to indicate the intensity of your current feelings. If you have a complete absence of the feeling described then place a vertical mark at the left edge of the horizontal line. If your feelings are the strongest intensity that you have ever experienced then place a vertical mark at the right edge of the horizontal line. If your feelings are between these two extremes, then use the distance from the left edge to represent the intensity of your feelings.

Example:

I feel I have no energy — Strongest feelings of energy ever felt

How do you feel right now with regard to your capacity to perform your typical PHYSICAL ACTIVITIES

I feel I have no energy — Strongest feelings of energy ever felt

I feel no fatigue — Strongest feelings of fatigue ever felt

I feel I have no vigor — Strongest feelings of vigor ever felt

I feel no exhaustion — Strongest feelings of exhaustion ever felt

I feel I have no pep — Strongest feelings of pep ever felt

I have no feelings of being worn out — Strongest feelings of being worn out

Figure 11. This image represents the screen that a subject would see when taking the CPT. The user would click in the white box, when ever the letter T was displayed. The image below is the screen the user would see before letters would appear.

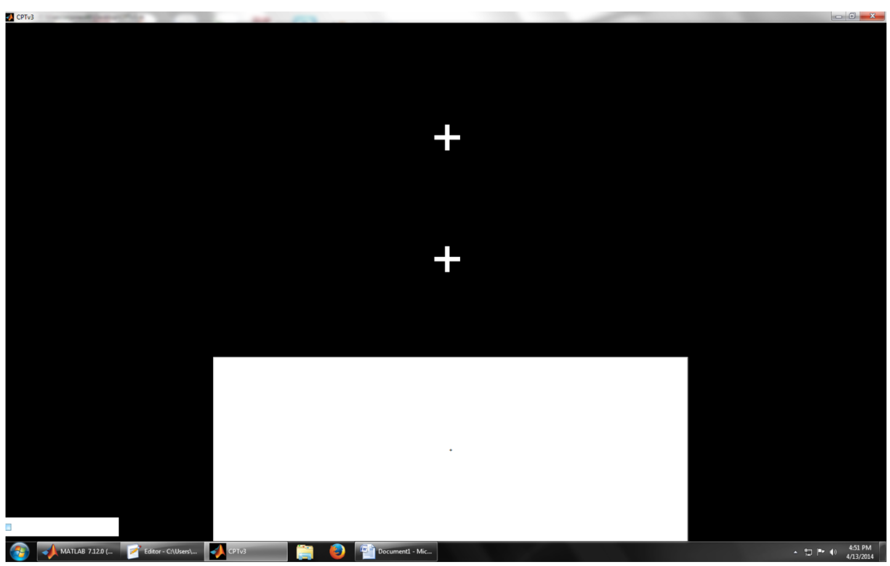


Figure 12. This figure represents the form that was used to record information specific to each subject. This form was only used during the exercise trial for each subject. Heart rate, RPE, RPM and Watts were recorded after a five minute warm up, for every 2.5 minutes and for a total of 35 minutes.

Cycle Test

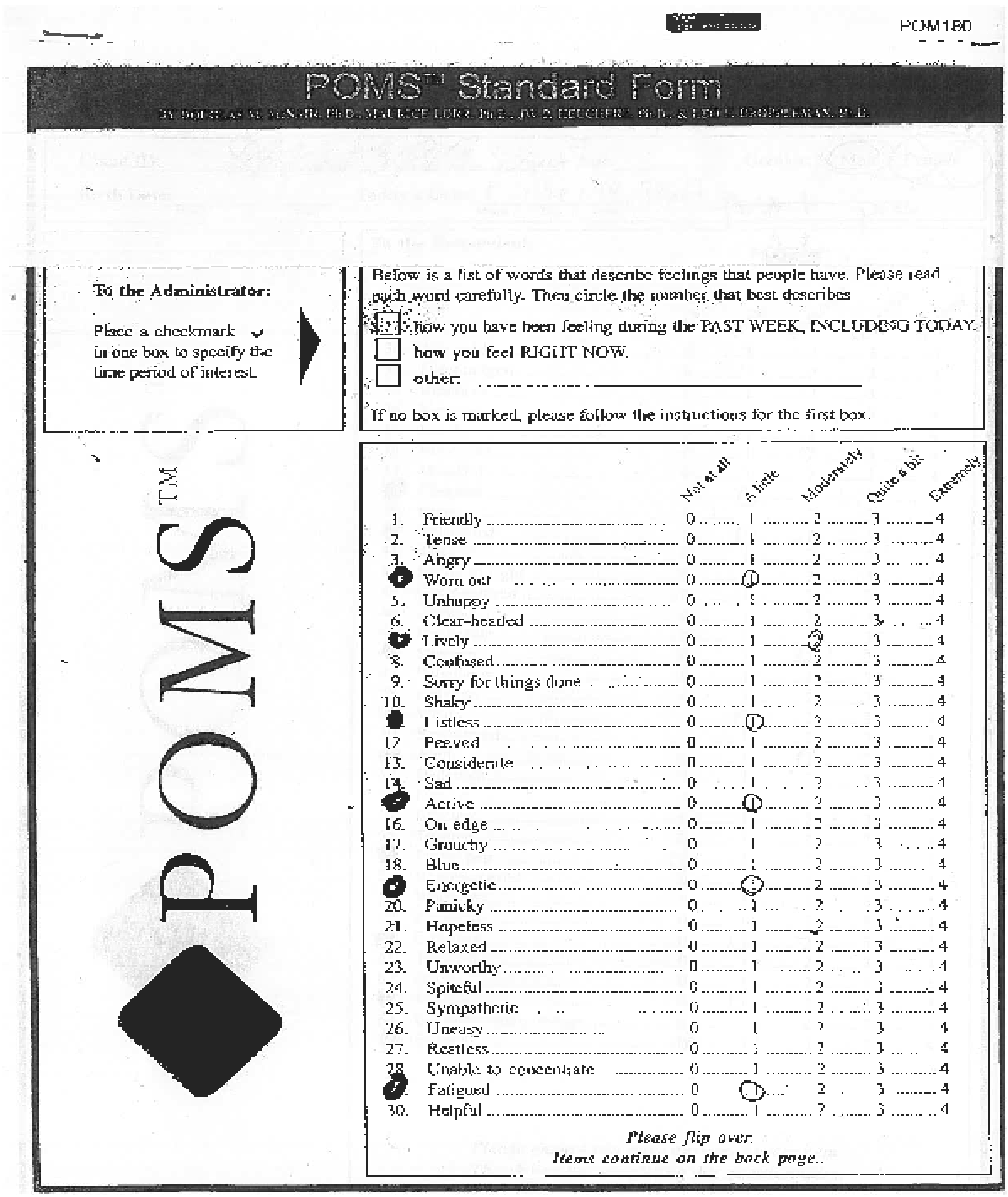
Name: ______________________________ Date: ___________________

Sex:_______ Height:___________ Nude Weight:____________ Age:___________

	Minute	HR	RPE	RPM	WATTS	Comments
Warm Up	5 min				50 Watts	
	7.5 min					
	10 min					
	12.5 min					
	15 min					
	17.5 min					
	20 min					

Minute	HR	RPE	RPM	WATTS	Comments
22.5 min					
25 min					
27.5 min					
30 min					
32.5 min					
35 min					

Figure 13. This is the documentation that was used to record a profile of moods state for each subject.



POM180

POMS™ Standard Form

To the Administrator:

Place a checkmark ✓ in one box to specify the time period of interest.

Below is a list of words that describe feelings that people have. Please read each word carefully. Then circle the number that best describes

- [✓] how you have been feeling during the PAST WEEK, INCLUDING TODAY.
- [ ] how you feel RIGHT NOW.
- [ ] other: ____________

If no box is marked, please follow the instructions for the first box.

	Not at all	A little	Moderately	Quite a bit	Extremely
1. Friendly	0	1	2	3	4
2. Tense	0	1	2	3	4
3. Angry	0	1	2	3	4
4. Worn out	0	1	2	3	4
5. Unhappy	0	1	2	3	4
6. Clear-headed	0	1	2	3	4
7. Lively	0	1	2	3	4
8. Confused	0	1	2	3	4
9. Sorry for things done	0	1	2	3	4
10. Shaky	0	1	2	3	4
11. Listless	0	1	2	3	4
12. Peeved	0	1	2	3	4
13. Considerate	0	1	2	3	4
14. Sad	0	1	2	3	4
15. Active	0	1	2	3	4
16. On edge	0	1	2	3	4
17. Grouchy	0	1	2	3	4
18. Blue	0	1	2	3	4
19. Energetic	0	1	2	3	4
20. Panicky	0	1	2	3	4
21. Hopeless	0	1	2	3	4
22. Relaxed	0	1	2	3	4
23. Unworthy	0	1	2	3	4
24. Spiteful	0	1	2	3	4
25. Sympathetic	0	1	2	3	4
26. Uneasy	0	1	2	3	4
27. Restless	0	1	2	3	4
28. Unable to concentrate	0	1	2	3	4
29. Fatigued	0	1	2	3	4
30. Helpful	0	1	2	3	4

Please flip over.

Items continue on the back page.

POMS™ Standard Form

BY DOUGLAS M. McNAIR, Ph.D., MAURICE LORR, Ph.D., JW P. HEUCHERT, Ph.D., & LEO F. DROPPLEMAN, Ph.D.

POMS™

	Item	Not at all	A little	Moderately	Quite a bit	Extremely
31.	Annoyed	0	1	2	3	4
32.	Discouraged	0	1	2	3	4
33.	Resentful	0	1	2	3	4
34.	Nervous	0	1	2	3	4
35.	Lonely	0	1	2	3	4
36.	Miserable	0	1	2	3	4
37.	Muddled	0	1	2	3	4
[redacted]	Cheerful	0	1	2	3	4
39.	Bitter	0	1	2	3	4
[redacted]	Exhausted	0	1	2	3	4
41.	Anxious	0	1	2	3	4
42.	Ready to fight	0	1	2	3	4
43.	Good natured	0	1	2	3	4
44.	Gloomy	0	1	2	3	4
45.	Desperate	0	1	2	3	4
[redacted]	Sluggish	0	1	2	3	4
47.	Rebellious	0	1	2	3	4
48.	Helpless	0	1	2	3	4
[redacted]	Weary	0	1	2	3	4
50.	Bewildered	0	1	2	3	4
[redacted]	Alert	0	1	2	3	4
52.	Deceived	0	1	2	3	4
53.	Furious	0	1	2	3	4
54.	Efficient	0	1	2	3	4
55.	Trusting	0	1	2	3	4
[redacted]	Full of pep	0	1	2	3	4
57.	Bad-tempered	0	1	2	3	4
58.	Worthless	0	1	2	3	4
59.	Forgetful	0	1	2	3	4
[redacted]	Carefree	0	1	2	3	4
61.	Terrified	0	1	2	3	4
62.	Guilty	0	1	2	3	4
[redacted]	Vigorous	0	1	2	3	4
64.	Uncertain about things	0	1	2	3	4
[redacted]	Bushed	0	1	2	3	4

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